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DESCRIPTION OF A NEW CRANIOMETER AND OF CERTAIN AGE CHANGES IN THE ANTHROPOID SKULL.

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The craniometer here described was designed to meet the following purposes:—

1. To record internal as well as external measurements of the skull.
2. To permit orientation of the skull in relation to certain internal points in place of the external points usually adopted.
3. To record the age changes of the exterior of the skull in relationship to these internal points. The inion, the opisthion, the basion, the meatus, the lower border of the orbit, and the glabella, change their positions during the growth of the anthropoid skull and are thus unsuitable for the purposes of orientation.
4. To estimate accurately the degree of asymmetry in the right and left halves of the skull.
5. To obtain measurements in a form that would permit one to produce an accurate composite drawing of a group of skulls.

Plane of Orientation.

The plane on which skulls were oriented may be called the *sub-cerebral.* Anteriorly the plane is fixed by the upper surface of the presphenoid and corresponds to the under surface of the deepest part of the frontal lobes. Posteriorly the plane is represented by a line joining the grooves for the lateral sinuses at the posterior-inferior angle of the parietal bones and corresponding to the lowest points of the occipital lobes of the cerebrum. It was thus possible to determine the cerebral height—a modification of Schwalbe's valuable calottal height. The bipolar length of the cerebrum is also obtained.

Description.

To illustrate the construction of the craniometer and its manner of use a human skull, bisected so that the reader may see how it is oriented, is shown in the measuring position in figs. 1 and 2; in fig. 1 the skull is placed in the vertex-up position for measurement of various points of the calvarial region; in fig. 2 it is inverted for examination of the basal region. The skull rests on a movable or orienting rod B B′ thrust within the undivided skull at an aperture made by a drill at the level of the lateral sinuses and exactly in the mid-sagittal plane. The rod is made of steel, 3 mm. in its horizontal and 5 in its vertical diameter. The orienting rod is graduated and passes through a vernier placed behind the upright plate (F), and may be pushed forwards in front of the vertical plate for an extent of 200 mm. By this rod it is easy to determine the position of the following points in the antero-posterior plane: (1) the dorsum sellæ; (2) the olivary eminence and optic groove; (3) the position of the right and left frontal poles of the brain. When the interior of the skull is artificially illuminated, the anterior end of the cribriform plate can also be determined. When the human skull is inverted (see fig. 2) and the rod pushed within it to an extent of 130–140 mm., the skull is supported at two points—at the sub-occipital perforation and at the presphenoid surface. The skull is oriented then on the sub-cerebral plane. On each side of it is a plate

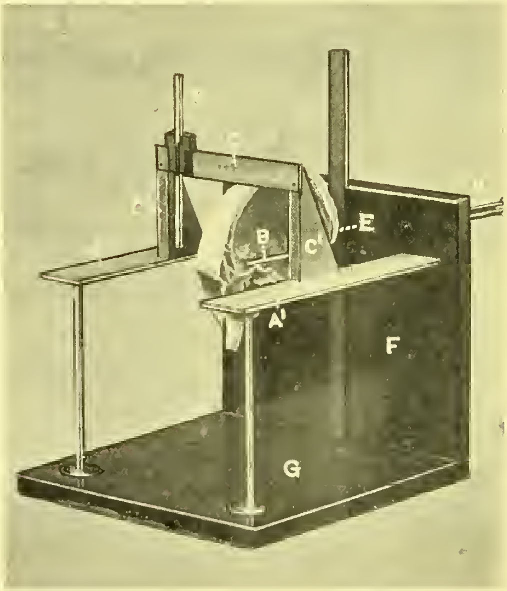

Fig. 1.—Craniometer with skull (208 mm. long). The skull is bisected in the specimen shown in order to show the position of the orienting rod B B.

A, A′, lateral plates, marked with millimetre scale, zero being at their commencement at the vertical plate (F); B B′, orienting rod; it works along a vernier placed behind the vertical plate (F); C, the bridge; C′ C′, uprights of bridge; D, sliding indicator on bridge; E, zero-point, where orienting rod perforates the vertical plate; F, vertical plate; G, foot-plate.

of wood (A A′) placed on exactly the same plane as the orienting rod. The *lateral plates* are graduated in the millimetre scale, zero being placed at their commencement from the vertical plate (F in figs. 1 and 2) against which the occiput of the skull rests. The position of any point of the skull is determined by a movable bridge (C), which glides on and at right angles to the lateral plates. The bridge has a space of 180 mm.; its uprights C′ C′ are sufficient to clear a skull with a calottal height of 120 mm. By means of the sliding vertical indicator (D) the position of any point can be determined in the antero-posterior plane (by the scale on the lateral plates), and in the vertical plane—distance above or below the sub-cerebral plane—by the vernier on the vertical indicator (D). The distance to each side of the median sagittal plane can be determined by means of the scale on the horizontal plate of the bridge. As these points are determined they may be plotted out on millimetre paper, and thus composite pictures of a single skull or of a group of skulls may be obtained such as are shown in figs. 3, 4, 5, 6. When the skull is placed in the inverted position on the orienting rod (fig. 2) the upper surface of the lateral plates corresponds to the upper surface of the orienting rod and therefore to the sub-cerebral plane; but in

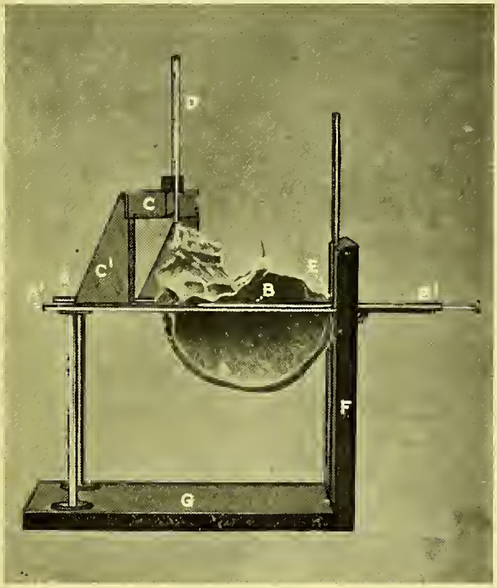

Fig. 2.—Side view of craniometer with skull inverted for measurement of its basal parts. Lettering as in fig. 1.

the natural position of the skull this plane is represented by the lower surfaces of the lateral plates—for the plates have the same thickness as the orienting rod. The instrument was made for the Royal College of Surgeons, England, by Stanley & Sons, High Holborn, London.

Application and Results.

The difficulties encountered in applying this instrument and the advantages gained by its use may be best illustrated by taking an actual instance. The skull chosen is that of a Bushman—No. 1674 R.C.S. Museum. The first difficulty is the determination of the exact point at which the occipital perforation has to be made so as to obtain the posterior limit of the sub-cerebral plane. The perforation is 3 × 5 mm., and does not in any way detract afterwards from the scientific value of the specimen; it adds to its worth, seeing that we gain access for the study of the interior. At first I selected the upper border of the lateral sinuses at a point 20 mm. to each side of the mid-sagittal plane. But this method I had to abandon—(1) because of the great discrepancy in the position of the right and left sinuses below the occipital poles, owing to the preponderating development of one side, usually the left; (2) because one or both of the sinuses may be very indifferently marked in this region. I have come to the conclusion that the best marks for indicating the posterior part of the sub-cerebral plane (or cerebro-cerebellar plane) are the lateral sinuses as they groove the posterior-inferior angles of the parietal bone. To fix the skull in the sub-cerebral plane (or approximately in that plane), in order to make the occipital aperture for the orienting rod, a fine hole is drilled midway between the upper and lower borders of the lateral sinus, as near the asterion as may be, and through these holes is thrust a long needle (a hat-pin answers), which thus transfixes the skull. The skull is then placed between the horizontal plates of the craniometer so that it rests at each side on the hat-pin, while the roofs of the orbit rest also on supports placed in the sub-cerebral plane. When thus placed, the point at which the occipital aperture must be drilled is easily indicated. When the perforation is made, the skull is placed in position and the orienting rod pushed within it until it touches the frontal wall in the plane of the ophryon (see fig. 3); this point I use as the position of the frontal pole for the reason to be given presently. After determining both frontal poles, the orienting rod is withdrawn until the skull rests on the presphenoid plate (see fig. 3). The positions of the inion, opisthion, the upper meatal point, basion, etc., are determined, their position being indicated on the millimetre paper. For instance, the inion is marked $\frac{10}{0}$; that is, it is 10 mm. forwards and exactly in the sub-cerebral plane; the basion is marked $\frac{80}{32}$; that is, it is 80 mm. forwards in the a.p. plane and 32 below the sub-cerebral plane. If necessary, the position in the lateral plane may also be added. Note is also made of the plane of the occipital condyles. In fig. 3 the low position of the basion and the shallow mastoid are indicated with an exactitude which cannot be obtained by any other method.

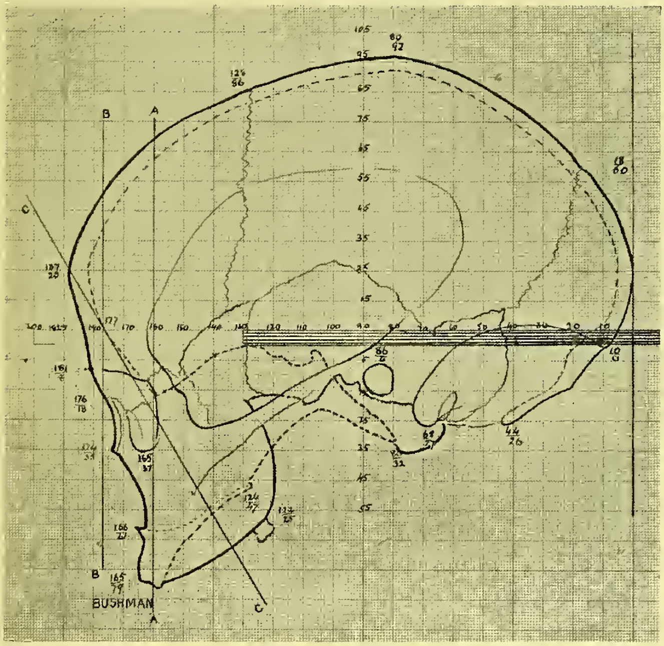

FIG. 3.—Drawing of a Bushman's skull (1624 R.C.S. Museum) made from craniometric data. The upper figure, shown at the chief points of the skull, gives the position of the point in the antero-posterior plane; the lower one in the vertical plane. The three vertical lines are drawn through the anterior end of the cribriform plate (A A); through the anterior pole (B B), at level of the ophryon; through anterior pole (C C) but at right angles to the ethmoidal plane. The orienting rod is represented by the bar of black lines—the lower margin of the rod—which is 5 mm. thick, representing the sub-cerebral plane. The rod is thrust within the skull to a distance of 140 mm.

The remarkable protuberant median frontal boss of the Bushman is a well-known character, but it is only by such a method as this that its nature can be ascertained. The forehead projects far in front of the eyebrows. In nearly all human races the glabella falls about 5 mm. above the sub-cerebral plane, but in the Bushman it falls below it. The cribriform plate is 2 or 3 millimetres below this plane as a rule in European skulls, but in the particular Bushman investigated it falls over 20 mm. below it. We are dealing here with a very remarkable bending of the base of the skull at the spheno-ethmoidal junction, a flexure which throws the upper part of the frontal lobe far in front of the lower part, the part which in most Europeans and all primitive races—for the Bushman shows many signs of being a remnant of some long-lost civilisation—forms the natural frontal pole of the brain. The skull shows an unusual degree of bending of the cranial axis at the spheno-ethmoidal junction, a bending which upsets—as Huxley knew—all methods of estimating prognathism.

ESTIMATION OF PROGNATHISM.

In my earlier investigations I regarded that point of the frontal lobe which lies immediately behind the ophryon as the frontal pole and used a vertical line (see fig. 4), drawn through the frontal pole at right angles to the plane on which the skull is oriented, as a base line from which to estimate the degree of prognathism and of nasal and orbital projection. When I came to deal with Negro skulls, especially with those of Bushmen, I found that the upper part of the frontal lobe projected further forwards than the cerebral poles. My aim was to obtain an exact method of estimating the degree of facial prognathism by stating in millimetres the degree by which the several parts of the face—the glabella, nasion, nose, nasal spine, alveolus, and chin—projected in front of the anterior cerebral pole; but my method, which answered so well for anthropoids and primitive man, was altogether upset by the condition found in the skulls of negroids. The ethmoidal part of the cranial base represents the axis on which the face is set; but a line drawn at right angles to the ethmoidal base is useless for the estimation of prognathism. The degree of prognathism is dependent on several factors, as Dr Duckworth has pointed out: (1) on the size of the teeth and palate, especially on the length of the palate; (2) on the size of the naso-pharynx, which may be estimated by the distance from the pharyngeal tubercle of the basi-occipital to the palatal spine; (3) in the degree to which the base of the skull is bent at the spheno-ethmoidal junction. These three factors must be estimated separately. The most satisfactory index of gnathism is the area of the palate, estimated by plotting out the diameters of the palate on millimetre paper.

On the other hand, a satisfactory method of estimating the degree of the occipital projection of the skull and brain may be worked out. At present I express the degree of occipital projection by the position of the inion. For instance, in the skull shown in fig. 3 the occipital projection is expressed by $\frac{10}{20}$: viz. that the occiput projects 10 mm. behind the inion and that the most projecting point is 20 mm. above the sub-cerebral plane. At present there is no exact method of recording this character. The calottal height—the highest point of the vault above the sub-cerebral plane—is 97 mm.; the corresponding cerebral height is 91 mm.; the bipolar (cerebral) diameter is 176 mm. The method brings out the slight supra-orbital and glabellar formation of the bush people. The development of the mastoid process and of the plane of the occipital condyle finds an exact expression by this method.

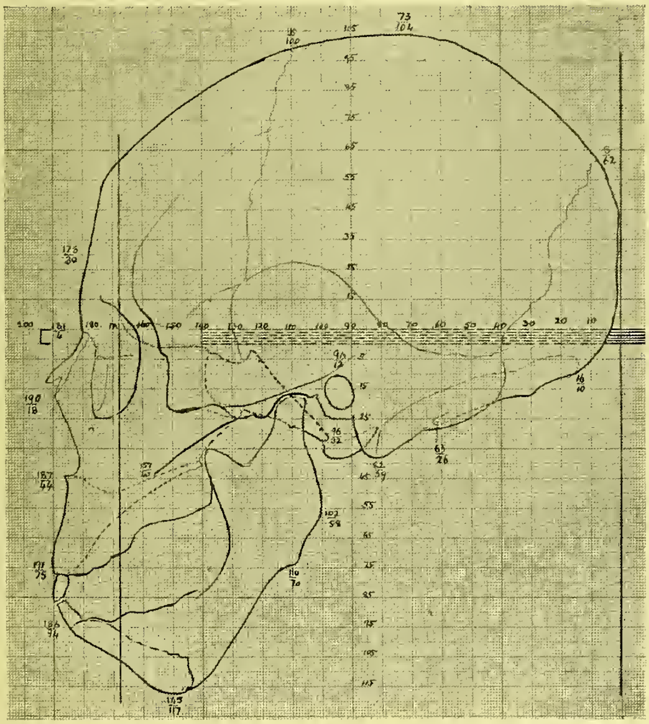

Fig. 4.—Craniometric drawing of the skull of a woman—a native of Johanna Island off Madagascar, showing a remarkable degree of prognathism due to an arrest in the growth of the spheno-ethmoidal part of the base of the skull. For explanation of the measurements see fig. 3.

A Remarkable Madagascar Skull.

As another example of the new light likely to be thrown on obscure craniological problems by the use of this method of examination, I would instance the results obtained (fig. 4) in a skull showing an extreme degree of prognathism. The skull is that of a woman, a native of Johanna Island, off Madagascar, which Mr F. G. Parsons gave me the opportunity of examining. The skull has been presented to the Museum of the Royal

College of Surgeons by the Medical School of St Thomas's Hospital, so that others may have an opportunity of examining it. The degree of prognathism is measured in the manner just mentioned, viz. by drawing a vertical line through the polar point and estimating the projection in front of this vertical. The polar point is 167 mm. from the occiput; the glabella projects 14 mm., the nose 23, the nasal spine 18, the upper alveolar point 24, the lower alveolar point 19, in front of the polar point, while the chin lies 22 mm. and the fronto-malar junction 5 mm. behind it. The figure also shows the position of the points below the sub-cerebral plane. In the majority of European skulls the anterior alveolar point lies, not in front of, but behind, the polar vertical, whereas in the Madagascar skull it lay 24 mm. in front of it. The prognathism is 24 mm. The nature of the prognathism is rendered apparent from an examination of the spheno-ethmoidal region of the skull. The distance from the pituitary fossa to the anterior polar point is 15–20 mm. less than normal. There has been an arrest in the development of the part of the spheno-ethmoidal base of the skull, whereas the facial part has attempted to reach its normal size upon a contracted cranial base, thus giving the effect of prognathism while the real condition is an atrophied base. The brain has expanded backwards, with the result that the opisthion, basion, and meatus occupy an abnormally forward position. The mastoid part of the temporal bone is stretched in an antero-posterior diameter. The measurements usually taken—the maximum length, breadth, and height—would reveal none of these peculiarities. The extraordinary hypertrophy of the alveolar part of the upper and lower jaws, combined with the atrophy of the spheno-ethmoidal part of the base of the skull, raises the supposition that we may be dealing here with a condition allied to acromegaly.

ANTHROPOID SKULLS.

As examples of the results obtained in the investigation of anthropoid skulls, figs. 5 and 6 are given. They represent the skull of a female chimpanzee (fig. 5) in which the third molar is cutting, and of a female adult orang (fig. 6). It is at once seen that the face of the anthropoid occupies a very different relationship to the cerebral cavity to that seen in the human skull. In European skulls the glabella falls on or below the sub-cerebral plane; in the Madagascar skull just figured, and in that of paleolithic man, the glabella and supra-orbital ridges rise from 5 to 15 mm. above this plane, but in the anthropoids it is placed at a much higher level, 30 to 35 mm. above the sub-cerebral plane in adults. But in the young this is not so; the glabella occupies a lower position, nearer to that of man. From figs. 5 and 6 it will be seen that the face covers the frontal lobe and that the part represented by the forehead of man is usurped by the supra-orbital ridges in the adult anthropoid.

In the anthropoid skull, when oriented in the sub-cerebral plane, the bregma is the highest point—a feature never observed in man. The calottal heights of the two specimens here figured are: 54 for the orang, 60 for the chimpanzee. Yet the height as measured from the auditory meatus is practically equal—68 mm. in the orang, 69 in the chimpanzee.

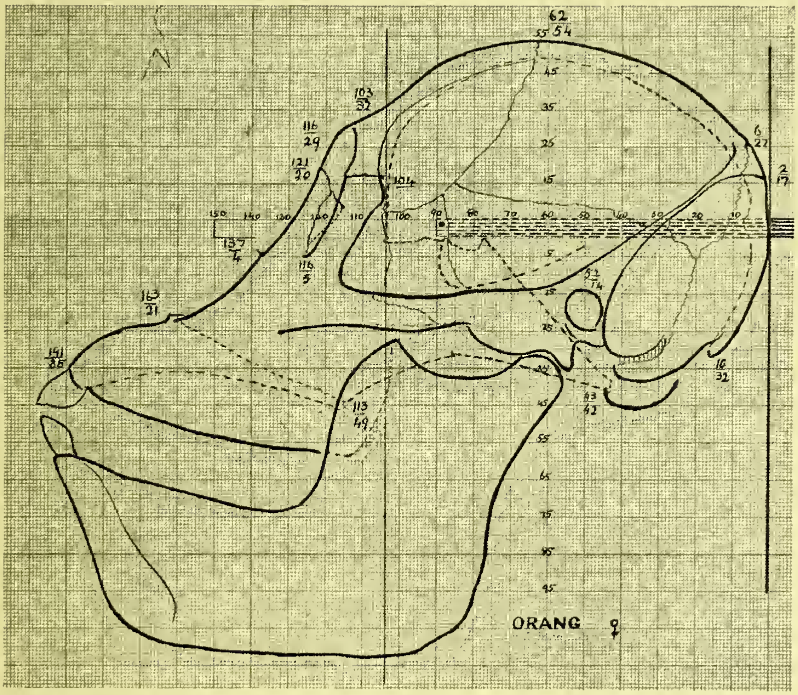

Fig. 5.—Craniometric drawing of the skull of an adult female orang. The orienting rod is represented within the skull—thrust in 90 mm., and resting on the presphenoid. The vertical line is drawn through the anterior polar point.

The degree of prognathism can be measured with accuracy if the vertical polar line be used as a base. The glabellar projection in the orang is only 12 mm., it is 25 mm. in the chimpanzee; the nasion 17 in the orang and 22 in the chimpanzee; the nasal tip 33 in the first, 27 in the second; the nasal spine 59 in the first and 38 in the second; the alveolar point 87 in the first and 57 in the second. The projection in the chimpanzee is a frontal projection, that in the orang a maxillary. It will also be seen that while the maximal lengths of the skull in the two specimens compared are 116 : 141, the maximal length of the brain is 99 : 111. The difference is chiefly in the skull, not in the brain.

Age Changes in Anthropoid Skulls.

One of the reasons which led me to select internal points on which to orient the skull was the experience I gained some fifteen years ago when carrying out an elaborate investigation on the age changes of the anthropoid skull. I saw that much of my work was rendered of little value because I had taken no cognisance of the relationship of the external to internal cranial points. The age changes in the anthropoid skull have little or nothing to do with brain growth—for by the end of the first year, if not earlier, their brains have ceased to grow. The vast changes which occur in the skull after birth are due mainly to three factors: (1) the eruption of the teeth and increase of the jaws to accommodate the increased dentition—a subject I have dealt with in the *British Journal of Dental Science*, 16th June 1902; (2) the growth of the muscles of mastication, and especially of

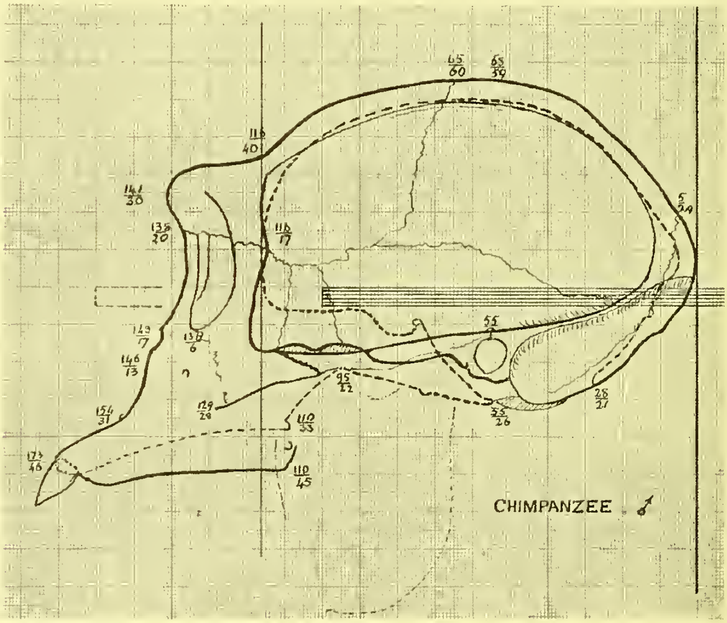

Fig. 6.—Craniometric drawing of the skull of a male chimpanzee, in which the third molar is cutting. For explanation of data see fig. 3.

their area of origin from the cranium—changes which I described in a paper published, rather obscurely, in the *Proceedings* of the Singapore Branch of the Royal Asiatic Society in 1891; (3) the modification of the "nuchal area" of the skull—the area to which the muscles of the neck are attached. The modification of the nuchal area is correlated with the growth of the jaws. The modification of the skull as a basis for the muscles of mastication has been accurately investigated by Professor Symington.

CHANGES CONNECTED WITH THE MUSCLES OF MASTICATION.

These changes are more marked in the skull of the gorilla than in any of the other primates, hence I have used the various stages of growth in this genus as a standard or scale for the conditions seen in other primates. In fig. 7 I have represented the skull of a gorilla in which the milk dentition is just complete (probably fifteen months old) set within the outline of the skull of an old male. The parietal bone, from its lower to its upper border, is divided into tenths, and also from its anterior to its posterior border. On the bone I have represented the extent to which the temporal ridge or line ascends at the edge of the expanding temporal muscle, as a wave of growing bone, the changes which occur from birth to old age, as observed

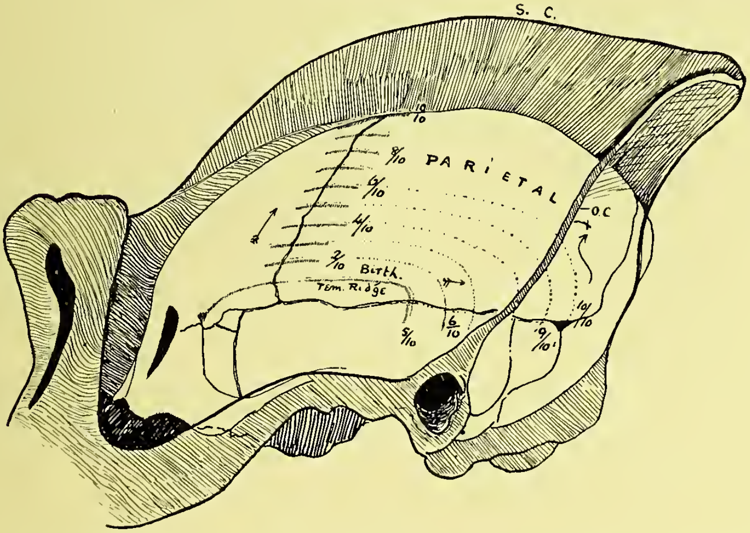

FIG. 7.—Showing the ascent and backward growth of the temporal ridges of the gorilla on the parietal bone. The skull of a gorilla in which the milk teeth have just cut is represented within the shaded outline of an adult male animal. The directions in which the temporal ridges spread are shown by the arrows; they finally form the great sagittal and occipital crests—(S. C. and O. C.).

in the various collections of anthropoid skulls in the public museums of London. The condition of the dentition was accepted as a key to the approximate age of the individual. At birth the position of the temporal line is the same in all the great primates; it lies about 10 mm. above the lower border of the parietal bone. Near the mid point of the lower border the line of temporal attachment passes on to the squamosal. The rate of ascent for a male gorilla may be expressed thus: at the end of the milk dentition the temporal line has ascended three-tenths of the height of the parietal bone; by the time the first permanent molar has cut, five-tenths; by the eruption of the second molar the two lines have met over the sagittal suture; and by the eruption of the third molar they have fused to form a mesial sagittal crest. In old males the crest has reached a height of 22 mm. or even more in the posterior part of the skull. The ascent of the lines is greatest in the gorilla, because it possesses a greater dental development than any other of the great or massive anthropoids. In the male orang, which in size of teeth comes nearest to the gorilla, the ridges form a crest 3 or 4 mm. high in the average individual, but in some, especially those with a large cranial capacity, the lines do not quite meet. In the male chimpanzee the lines remain a little distance apart or just meet, and in only very old individuals is a crest formed. In six old chimpanzees the mesial sagittal crest had a mean height of just under 2 mm. In the Siamang and also the Hylobates leuciscus the ridges are arrested at a point eight-tenths of the way up the parietal bone. In the European the ridges are arrested at a point about four-tenths up the parietal. It will be thus seen that the temporal lines in man are arrested on the parietal at a point reached in the gorilla very soon after the eruption of the milk dentition; in the gibbon they are arrested permanently at the position reached in the gorilla after the eruption of the second permanent molar; in the adult chimpanzee the ridges occupy the same relative position as in a gorilla with the canines cutting, and in the adult orang they are arrested at the point reached in an immature male gorilla. The permanent form in man and anthropoids represents arrested stages in the development of the gorilla's temporal ridges. In the chimpanzee and orang there is a great degree of individual variation as regards the position of the temporal ridges.

There is another factor which determines the position of the temporal lines besides the size of the muscles, and that is the size of the brain. The bigger the brain the greater the dimensions of the parietal bone. So great is the growth of the parietal bone during the first five years of life in man that the relative position of the temporal line remains almost unchanged; but when the first permanent molar is cut it begins to ascend, although the extent of its ascent is seldom more than 10 mm. In the male gorilla the actual ascent is over 80 mm. While the great size of the cranial cavity in man explains the relatively low position of his temporal ridges, this explanation does not hold for the three great anthropoids in which the brain is approximately of the same size.

In fig. 27 there is also represented the growth backwards of the temporal ridges until they ultimately meet and fuse with the occipital or nuchal ridge which ascends at the growing edge of the nuchal musculature. During the eruption of the milk teeth in man and in the three great anthropoids the temporal lines here extend backwards to five-tenths of the length of that bone; in adult man they reach 80 per cent. of the parietal length; in the adult chimpanzee they reach the posterior end of the bone and meet the nuchal line on the mastoid part of the temporal and on the occipital. In the gorilla and orang the posterior border is reached before the third molar cuts, and in the adults of these genera the temporal and occipital ridges fuse to form the great lambdoidal crests. It will be thus seen that in the more microdont of the orthograde primates—man and the chimpanzee—the temporal ridges of the adult correspond to immature stages in the orang and gorilla.

SEXUAL DIFFERENCE.

There is a marked difference in the development of the temporal lines of the male and female of the three great anthropoids, as may be expected from the difference in the size of their dentitions. The stage in the adult female corresponds to that seen in the immature male. In the average female gorilla the temporal lines just meet on the vertex of the skull; in the male they form a crest which may be 22 mm. or more high. In the female orang they stop 10 mm. short of the sagittal suture; in the female chimpanzee they are arrested, as a rule, about 25 mm. from the mid-sagittal line. In woman they do not ascend so far as in man, but the sexual difference is less marked. In gibbon the sexual difference in this respect is very slight, a condition which follows from the equality of their dental development. It will be observed that in the development of the temporal ridges, as in the strength or robustness of dentition, the gorilla and man mark opposite extremes.

GROWTH IN THE BREADTH OF THE BASE OF THE SKULL.

The inflation of the basi-sphenoid and ali-sphenoids by the sphenoidal air sinus in the great anthropoids and a corresponding inflation of the squamous part of the temporal bone, all of which changes commence with the eruption of the permanent teeth, bring about a great increase in the breadth of the base of the skull. The amount of increase may be measured from the extent to which the condyles of the lower jaw move apart from birth to old age. It will be observed from the table I give that the breadth of the skull of the newly-born gorilla, chimpanzee and orang is nearly the same. While the breadth of the skull of the gorilla increases 74 mm., the increase in man and the chimpanzee is only about 50 mm. To a large extent the growth in width in man is due to a great increase of cranial capacity, while this factor has very little to do with the increase in the giant anthropoids.

TABLE SHOWING THE DISTANCE BETWEEN THE OUTER ENDS OF THE MANDIBULAR CONDYLES OF THE LOWER JAW AND THE HIGHER PRIMATES.

	During Milk Dentition.	Adult Males.	Increase.
	mm.	mm.	mm.
Gorilla, . . .	66	140	74
Orang, . . .	72	158	66
Chimpanzee, . .	64	110	46
Siamang, . .	40	72	32
Man, . . .	65	118	53

MODIFICATIONS OF THE NUCHAL AREA.

As the jaws and muscles of mastication increase in size the nuchal area is modified to give a wider and stronger attachment of the head to the trunk. The poise of the skull is altered, owing to the peculiar manner in which the jaws grow (see *British Journal of Dental Science*, 16th June 1902). The alteration gives the appearance of a forward rotation of the anthropoid face on the cranial cavity. The face of the adult covers what was the forehead of the infant anthropoid. Professor Sollas in his accurate description of the Gibraltar skull has referred to this rotation. The occipital region of the anthropoid skull becomes profoundly modified during the eruption of the permanent teeth. There is a threefold change: (1) the expansion of the area of nuchal attachment by the ascending and growing nuchal wave of bone which precedes the growth of the muscles of the neck (made up of mastoid and occipital segments): (2) there is the growth of the basilar plate of the skull—basi-occipital and basi-sphenoid—which appears to thrust the occipital condyles backwards (see fig. 9), but in reality pushes the facial part of the skull forwards; (3) there is an absorption or atrophy of that part of the occipital squama that bounds the foramen magnum behind. These changes are given a diagrammatic representation in figs. 8 and 9. In the composition of these figures I utilised the measurements made in our 130 anthropoid skulls, more than 70 of which were immature.

The growth of the nuchal area is greatest in the gorilla. With the ascent of the temporal ridges on the sides of the skull there is a corresponding movement in the nuchal lines over the occipital and mastoid parts of the skull, to give increased attachment to a rapid growth in the muscles of the neck. These changes are shown in fig. 8. From the eruption of the milk teeth to the close of the permanent dentition the nuchal ridge ascends on the occipital bone of the gorilla to an extent of 80 mm., until it meets with the temporal ridge and forms, by their fusion, the lambdoidal crest. The ascent in the male orang is 75 mm.; in the chimpanzee 47 mm.; in man 30 mm.; in the gibbon 30 mm. In all the giant primates—man, gorilla, chimpanzee and orang—the neck is about equally thick at birth and the area of nuchal attachment approximately equal. The nuchal expansion is greater in the male than in the female. In man and the chimpanzee the stage seen in immature orangs and gorilla is retained as the permanent form.

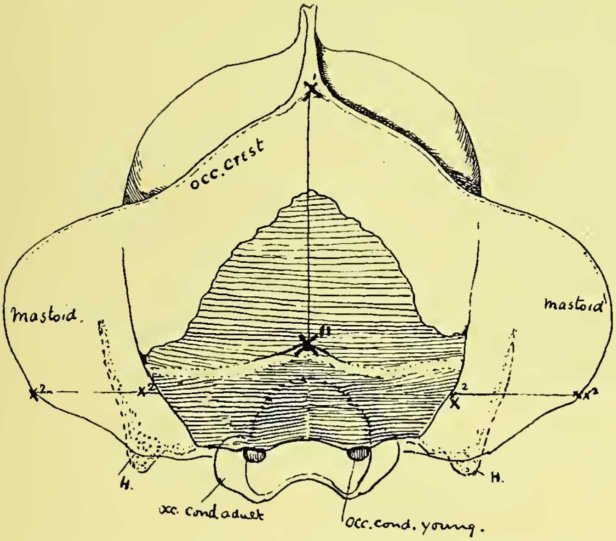

FIG. 8.—Diagram of the growth of the nuchal crests in the gorilla from youth (milk-dentation) to old age. The occipital bone of the young gorilla is shaded, and the position of the occipital part of the nuchal ridge or line is shown at X^{11} (the inion); the position in the adult at X^1. The distance between X^2 and X^2 represents the degree of lateral expansion from youth to maturity. The corresponding expansion in man is shown by H.

The expansion of the width of the area of nuchal attachment is obtained by the growth of the mastoid segments of the nuchal lines. The width of the nuchal area is about 90 to 95 mm. in the young of all the giant primates at the end of the eruption of the milk teeth. The mastoid part of the temporal bone forms part of the nuchal area and carries the lateral part of the expanding nuchal line or ridge. In the average adult male gorilla the mastoid part of the nuchal area has expanded laterally so that the total breadth has increased by 65 mm.; in the orang the increase is 55 mm., in the chimpanzee 38, and in man 35. The expansion in the width of the human skull is due chiefly to a growth of the cranial cavity; but in the anthropoid it is purely a mastoid growth. In man—or rather in modern man—the mastoid part of the nuchal line or ridge has become curiously modified to form the mastoid process. The incipient stage of this comparatively recent modification is seen in the Gibraltar (Neanderthaloid) skull. The expansion of the nuchal area is correlated with the dental development.

The nuchal breadth of the skull increases 100 per cent. from youth to old age in the male gorilla; 64 per cent. in the orang, 54 per cent. in the gibbon, 48 per cent. in the chimpanzee, and 44 per cent. in man. Taking the distance between the opisthion and inion in the young as a standard the nuchal crest may be said to ascend 110 per cent. in the male gorilla, 80 per cent. in the orang, 75 per cent. in the chimpanzee, and 30 per cent. in man.

GROWTH OF THE BASILAR PLATE AND MIGRATION OF THE OCCIPITAL CONDYLES.

In all young anthropoids the occipital condyles are situated on the under aspect of the skull, so that the head is poised with some degree of ease on the spine. With the eruption of the permanent teeth the basi-occipital bone begins to elongate (see fig. 9) and the occipital condyles are thrust—as regards the rest of the skull—further and further backwards, until, instead of lying on the under, they appear to be situated on the posterior or occipital surface of the skull. In fig. 9 there is given a diagrammatic representation of this change as observed in the gorilla.

The backward growth of the condyles was estimated by measuring the length of the basilar plate (from the basion to the posterior point of the attachment of the vomer to the sphenoid) in individuals at various stages of development. During the eruption of the milk teeth the basilar plate in the young of the giant anthropoids measures about 25 mm. The young of man and of the gorilla are distinguished by the shortness of the basi-occipital part. The greatest elongation of the basilar plate takes place in the gorilla. With the elongation of the basilar plate the condyles are thrust backwards, as shown in fig. 9; or, to be more accurate, the facial part of the skull is thrust forwards and upwards, the articulation of the condyles with the atlas preventing any real backward migration as regards their position relative to the trunk. The growth of the basilar plate throws the snout away from the cervical part of the spinal column so as to accommodate the great mandible masticatory apparatus.

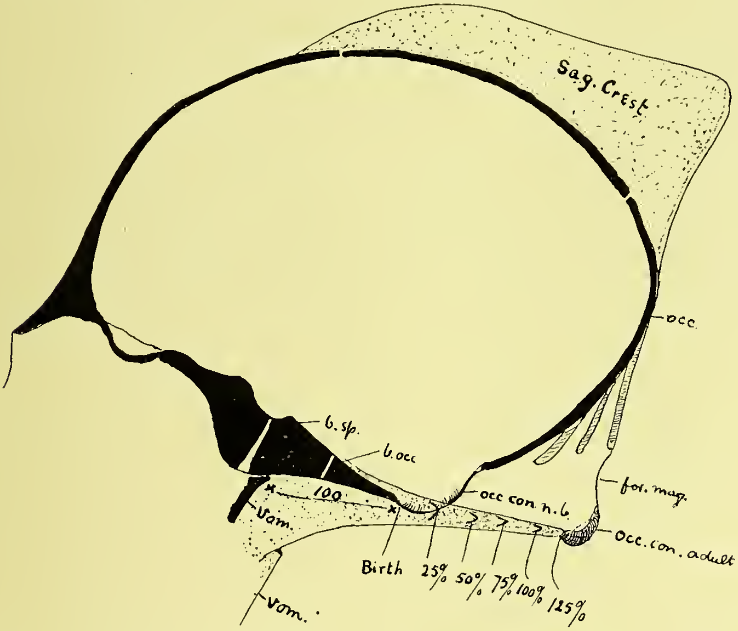

Fig. 9.—Diagrammatic representation of the changes in the basilar part of the skull of the gorilla from the end of the eruption of the milk teeth until adult age. The black outline represents a tracing of the young skull; the shaded and stippled areas, the growth changes. 100 = the length of the basilar plate at the end of the milk dentition; *occ. con. n.b.*, the position of the occipital condyles in the youngest stage; *occ. con. adult*, position in the adult; *for. mag.*, the foramen magnum.

Using the length of the basilar plate during the eruption of the milk teeth as a standard of 100, its increase in the male gorilla may be stated as 120 per cent., in the male orang 80 per cent., in the chimpanzee 70 per cent., in man 20 per cent. The Siamang and gibbon agree with the gorilla and pronograde apes, and show an increase of 110 per cent. In anthropoid apes this is a real growth, for their cranial capacity has reached its full size at the end of the eruption of the milk teeth. The axis of the skull is brought more and more into line with the axis of the spinal column. The condyles of the adult gorilla occupy, as regards the centre of the skull, a position which is 27 mm. further back than in the young animal. In man the posterior movement is not more than 5 mm., and this is chiefly due to cranial expansion. The infantile condition of the anthropoid becomes the permanent condition of adult man.

Modification of the Squama Occipitalis.

With the growth of the basilar plate in the gorilla and, to a less degree, the orang, chimpanzee and gibbon show similar changes, the squama occipitalis becomes shorter—the opisthion retreating towards the lambda (see fig. 9) and also becoming altered in form. The position of the cerebellum becomes altered; in place of being covered by the occipital lobes, the posterior cerebellar poles come to have the same degree of posterior projection as the cerebral occipital poles. The squama occipitalis becomes flattened. The plane of the foramen magnum moves from an obliquely horizontal to a plane almost at right angles to the base of the skull. The diagram given in fig. 9 is founded on measurements made on 130 anthropoid skulls, over 70 of which were immature.

Decrease of the Vertical Diameter of the Cranial Cavity.

The accurate data collected by Professor Karl Pearson and his pupils have shown that the cranial cavity in man reaches its maximum capacity about, or just before, the twentieth year. My observations show that the maximum size is reached much earlier in anthropoids—probably before the middle of the second year, when the milk dentition is completed. Using the condition of the teeth as a guide to the age of individuals there can be no doubt that in the great anthropoids, although the exterior continues to grow until old age, the cranial capacity actually decreases and this decrease especially affects the vertical diameter of the skull as measured from the upper surface of the presphenoid, just in front of the optic foramina, to the internal bregma. It is difficult to obtain a sufficiently large series of anthropoid measurements to prove definitely the vertical decrease, but in cats there can be no doubt that such a decrease does take place. The mean vertical measurement (presphenoid—internal bregma) is greater in a kitten of seven weeks than in the adult cat. I suspect that the pressure exerted on the skull by the temporal muscles has to do with the reduction.

Dr Charles Hose, to whom zoologists are so much indebted for gifts of primate material, supplied me with fourteen skulls of Hylobates leuciscus at various stages of growth.

In the adjoining table are given—

1. The condition of the teeth.
2. The maximum a.p. diameter of the cranial cavity.
3. The maximum width.
4. Its vertical diameter as measured from the presphenoid—just anterior to the optic foramina—to the internal bregma.
5. The relation of the breadth to length.
6. The relation of height to length.
7. The cranial capacity.

Animal.	1.	2.	3.	4.	5.	6.	7.
No. 1 ♀	$\frac{m^1}{m^1}$ cutting (permanent) molar.	66	56·3	39·2	85	60	89 cc.
„ 2 ♀	$\underline{m}^2$ cutting.	70·5	56·3	39·2	80	55	82 „
„ 3 ♂	m^3 cutting.	72·4	61	42·5	84	59	107 „
„ 4 ♂	$\underline{c}^2$ cutting.	73	62·5	38·5	84	52	104 „
„ 5 ♀	$\overline{m}^3$ cutting.	69·2	61	43·2	88	63	105 „
„ 6 ♀	$\underline{c}$ „	69·2	58	39·2	84	57	98 „
„ 7 ♂	$\frac{c}{m^3}$ „	68·2	58·5	39·2	86	57	99 „
„ 8 ♀	$\underline{c}$ cut.	69	58·5	41·2	85	59	95 „
„ 9 ♂	$\frac{m^1}{m^1}$ worn.	69	62·5	39·2	90	58	102 „
„ 10 ♂	$\frac{m^1}{m^1}$ „	69	58	39·2	80	57	104 „
„ 11 ♂	$\frac{m^2}{m^2}$ „	64·2	55	39·2	83	61	82 „
„ 12 ♀	molars worn.	69	59·4	59·2	86	57	108 „
„ 13 ♀	molar worn +	66	58	38·5	88	58	90 „
„ 14 ♀	molars worn +	67·6	59	36	85	54·6	92 „

Mean of 1–7	69·8	59·1	40·5
„ 8–14	67·7	58·6	39
Difference	2·1	·5	1·5

While it may be said that the data given in the above table supports the thesis that there is a reduction of the cranial capacity—a reduction of all its diameters, and that this reduction affects the vertical diameter in particular—yet the data cannot be held to prove the contention, owing to the limited number of specimens at my disposal. The animals from 1–7 are immature; those numbered from 8–14 are mature, but only three of them can be described as aged. The mean of the vertical diameter is 1·5 mm. less in the older than in the younger group, while the reduction in the a.p. diameter is proportionately less, viz. 2·1 mm.; the reduction in the transverse diameter is markedly less.

SUMMARY.

This paper deals with: (1) the description of a craniometer which gives definite records of the position of both the internal and external points in the skull; (2) descriptions are given of four skulls—that of a Bushman, of a peculiar skull from Johanna Island off Madagascar, of an orang and of a chimpanzee skull; (3) the following age changes in the anthropoid skull are described: (*a*) the ascent and expansion of the temporal ridges; (*b*) the expansion of the nuchal ridge (occipito-mastoid curved lines); (*c*) the posterior migration of the basion, occipital condyles, and opisthion.